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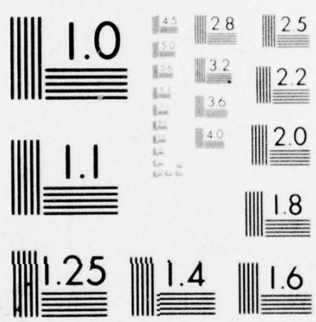

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Contract No. F44620-75-C-0040

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SURFACE REACTIONS

The broad concern of the research program during the last two years has been energy exchange phenomena that relate to problems of high speed and/or altitude flight conditions. The specific study areas divide into those concerned with particle interactions at a surface which is adjacent to a fluid and those for which radiative exchange between a surface and its induced disturbance field is of dominant importance to the energy transfer.

The gas-surface portion of the effort was motivated to a large extent by previous study of graphite oxidation which was carried out with a molecular beam system using dissociated oxygen. The radiation gas dynamics portion represents the culmination of analytical efforts to develop some understanding of coupling modeling and its influence on the predicted rates of energy transfer to a surface during flight situations.

I. GAS-SURFACE INTERACTION STUDIES

Molecular beam systems ideally simulate the events within a gas particle mean free path of a surface, and typically examine only a selected portion of the velocity spectrum effects as inferred from scattering patterns. Necessarily, the available signal levels are quite small and the surface equilibrium is upset by the imposed examination process. Our earlier studies made this very apparent in terms of the care required to record steady state reaction probabilities during graphite oxidation over extended periods of recording times.

One of our interests was therefore a specific consideration of the surface adjustment time to steady state (dynamic) equilibrium after a well defined exposure of a target to beam interactions and/or thermal soak. The procedure subjected a graphite target to an oxygen beam while at high surface ($T \approx 2000°K$) temperature for sufficient time to ensure a known and verified state, corresponding to a relatively inactive reaction rate. A sudden adjustment to alternate (lesser) temperature levels was accompanied by an experimentally monitored reaction probability history during the period of nonequilibrium surface relaxation. This provided insight into the relative importance of the reaction (activating) and thermal (annealing) influences.

The surface adjustment was fairly well established to be related directly to the number of oxygen particles impinged onto the surface ($\approx 2 \times 10^{20}$ per cm^2 to establish a steady state independent of pressure), and proved to require the order of $10\text{-}10^2$ hours. The time constants for such activation and relaxation processes enter into a realistic specification of empirical rate constants, and comparison of such constants with and without such consideration indicates their inadequacy at all but the highest pressures. This work is described in detail in an AFOSR report, was presented at the Tenth Rarefied Gas Dynamics Symposium in Aspen and is scheduled to appear in the Proceedings[1,2].

A second study followed from the appreciable differences in reaction probability that are observed for carbon monoxide resulting from atomic or molecular oxygen directed at graphite. The molecular form implies a probability less by an order of magnitude and presumably relates in some measure to the gas dissociation energy to be accounted for during the surface interaction. With this in mind, the probabilities of single and successive multiple collisions between gas and surface particles were examined for certain minimum interaction energy constant encounters. With only two collisions, the resulting activation energies from such modeling (in an extended hard cube sense) proved to be consistent with measurements for the temperature range in which reaction probabilities increase with temperature. Peak probabilities for activation also proved comparable to those found experimentally. At still higher surface temperatures, an appreciable number of effective collisions are required in order to match the observed rapid decline in experimental probabilities. The details are summarized in an AFOSR report[3].

An essential problem in carrying out reaction probability measurements with beam systems is the low signal level available for effectively carrying out point detection in the scattering half space. Extremely few of the incident particle flux to the target are actually counted by, e.g., a mass spectrometer scan in a given traverse plane, and for those there is a further separation by species (O_2, O, CO). Distinguishing between the primary signal and background noise by means of modulation techniques therefore involves long (electronic) integration times of the order of hours, which is extensive with respect to general equipment drift characteristics and demanding on the investigator. The above remarks with respect to the possible existence of comparable surface adjustment time constants emphasizes the importance of achieving smaller measurement time intervals. A third study was therefore focused on the characteristics of finite system components (detector, modulation collimator, target) in contrast to the familiar attempts to utilize point (ideal) components, i.e., separation distances between units large relative to the face dimensions. The proper interpretations or "corrections" were developed in terms of such component scales, detection angle, with and without collimator shielding, and for a family of cosine power intensity distributions. Potential signal level enhancement of the order of 10^2 to 10^4 factors are in fact realizable with proper interpretation of measurements in terms of such "correction" characteristics. Similarly, comparisons of results from distinct systems often require such considerations even when closely "ideal." The work is described in a recent AFOSR report[4].

II. RADIATION COUPLING STUDIES

The nonlinear nature of the fluid field description has led to numerous approximations of both a physical and mathematical kind. The inclusion of radiation as an appreciable energy exchange phenomenon requires special considerations for possible simplifications in view of the integro-differential description implied by such an interaction. Two types of simplifications appear most frequently in applications: either a (locally) one-dimensional radiation field superimposed on a general fluid field, or a (local) differential approximation embedded within such a field.

We have developed an extension of the classical differential approximation which provides a capability for matching an extreme range of nonisotropic radiation. The technique is most easily visualized as ellipsoidal intensity modeling, with the potential of ellipsoidal orientation, offset, and eccentricity to affect improved representations of actual intensity distributions at a field point. Mathematically, this permits higher order moment modeling corresponding to a formal spherical harmonics expansion. The field itself furnishes the ellipsoid description locally and thereby a variable closure method in the sense of an extension of the classical Milne-Eddington assumption of the moment correspondence.

The utility and accuracy has been demonstrated in comparisons with exact and differential approximation field solutions for typical shock layer like volumes (rhomboids, concentric cylinders, annular conical). The method proves quite reliable including in the especially nonisotropic sharp corner regions. Fully coupled gas dynamics examples for wedge shock layers have shown marked departures in intensity distributions when allowance is made for the nonisotropic field. The work is summarized in a detailed AFOSR report and in two papers[5,6,7].

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